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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The objective of this research is to characterize high T_c superconductors with longitudinal and transverse ultrasonic waves. Both attenuation and velocity measurements have been performed on sinter forged samples of $YBa_2Cu_3O_7$, which has two CuO planes perpendicular to the c-axis per unit cell. Three elastic constants, C_{11}, C_{33} and C_{44}, out of five, for this axially symmetric sample, with 80 percent of the c-axis of platelet like crystallites aligned along the forging axis, have been determined. Three maxima in attenuation are observed at 70 K, 180 K and 250 K when longitudinal waves are propagated perpendicular to the forging axis. Only the middle maximum is observed when either longitudinal or transverse waves propagate parallel to the forging axis or perpendicular to CuO planes. Thus, the middle maximum may be due to an isotropic interaction while the other maxima -> are

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19. Abstract - continued

may be produced by interactions associated with distortions of the CuO planes. Frequency dependent measurements on sintered samples of $YBa_2Cu_3O_7$ show that the low temperature maximum is produced by a relaxation mechanism. The activation energy of the relaxation time for this maximum is about 400 K which is near the Debye temperature of this compound. Sound measurements in a sample of $Ba_{0.625}K_{0.375}BiO_3$, which has a T_c = 28 K and which is postulated to be a BCS superconductor, show a maximum in attenuation around 50 K. Attenuation measurements in UPt_3 as a function of magnetic field exhibit a peak in the mixed state. This peak is indicative of a phase transition in the flux line lattice of this anisotropic superconductor. Since high T_c superconductors are highly anisotropic, it is expected that measurements on other anisotropic superconducting systems will provide insight into the characterization of high T_c superconductors.

Annual Summary Report

Bulk Wave Characterization of High T_c Superconductors

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November 1, 1988

ANNUAL SUMMARY REPORT

I. Description of Project

The investigation will characterize high T_c superconductors with longitudinal and transverse ultrasonic waves. The frequency, temperature, and magnetic field dependence of the attenuation and velocity of ultrasonic waves in the new classes of superconductors, which include the perovskite phase, the tetragonal phase, and the newly discovered copper free superconducting compounds, should help to determine if the attenuation maxima, which have been observed in some of these samples, are due to relaxation processes which could be associated with excitons, spin density waves, soft polarons or small plasmons which may be responsible for the superconducting properties of these compounds. Measurements in the superconducting state will determine the nature of the interaction, which may help to select between the different theoretical models that have been proposed to explain superconductivity in these systems.

II. Scientific Approaches

Both longitudinal and transverse waves up to frequencies of 4 GHz will be used to characterize the superconducting samples as a function of temperature, frequency and magnetic field. Initially, these measurements are being performed on sinter pressed and sinter forged samples. The latter samples provide a compromise in the goal of measuring single crystals, since these samples are composed of grains whose c-axis is oriented within 20° of the forging axis. Measurements will be performed on single crystals when sufficiently large specimens become available.

Measurements will be done from room temperature down to millikelvin temperatures in those samples which undergo magnetic transitions at low temperatures. The effect of oxygen concentration on attenuation and elastic

constants will be investigated in order to determine if there are lattice phase transitions associated with the step-like changes in T_c produced when the number of oxygen atoms in $YBa_2Cu_3O_7$ is continuously decreased from seven to six.

III. Accomplishments

A. Sinter Forged $YBa_2Cu_3O_7$

Sinter forged samples of $YBa_2Cu_3O_7$ prepared at Northwestern University are composed of platelet shaped grains about 11 μm thick and 37 μm in diameter, with the c-axis perpendicular to the grain face. Eighty percent of these crystalites have their c-axis aligned within 20° of the forging axis. Therefore, these samples provide a reasonable system for investigating the anisotropic behavior of these perovskite superconductors until single crystals which are sufficiently large for ultrasonic measurements become available.

Longitudinal and transverse waves were used to measure the dependence of both the attenuation and the elastic constants in sinter forged samples of $YBa_2Cu_3O_7$. Longitudinal waves were propagated parallel and perpendicular to the forging axis, and transverse waves were propagated parallel to the forging axis. This perovskite superconductor contains two CuO planes per unit cell which are perpendicular to the c-axis.

The perovskite structure has nine elastic constants. These may be reduced to five when the axial symmetry of the sinter forged samples is taken into account. The above measurements yielded room temperature values for three of these $C_{11} = 1.17 \times 10^{12}$ dyne/cm^2, $C_{33} = 0.86 \times 10^{12}$ dyne/cm^2 and $C_{44} = 0.43 \times 10^{12}$ dyne/cm^2 . It is noteworthy that $C_{11} > C_{33} = 2\ C_{44}$. This implies that it is twice as easy to shear the CuO planes in a unit cell than to compress them, and that is harder still to distort them, when a longitudinal wave travels along the CuO planes.

There was hystersis observed in the temperature dependence of C_{33} and C_{44}. This hystersis may be due to a strain arrested first order phase transition which is associated with domain wall motion in the crystallites, similar to what has been observed in ferroelectic materials with similar grain structures.

When the attenuation of 12 MHz longitudinal waves propagating perpendicular to the forging axis or parallel to the CuO planes was measured as a function of temperature three local maxima were observed at 70 K , 180 K and 250 K. Only the middle maximum was observed with 12 MHz longitudinal or 14.5 MHz transverse waves propagating parallel to the forging axis or perpendicular to the CuO planes. This maximum moved to a higher temperature when 41 MHz transverse waves were used, indicating that the maximum is due to a relaxation process. And, since it is observed in both orientations, it may be due to an isotropic interaction. The other two maxima are only observed when the CuO planes are distorted. Therefore we may assume that they are produced by interactions which are associated with distortions in the CuO planes.

Measurements with transverse waves propagating perpendicular to the forging axis are in progress in order to obtain C_{66} and propagating at 45° to the forging axis in order to obtain C_{13}.

B. Sintered $YBa_2Cu_3O_7$

The three attenuation maxima that have been observed in the sinter forged samples have also been observed in sintered samples of $YBa_2Cu_3O_7$ where the grain size is just a few μm's; and, there is no observable anisotropy. This is one reason why it is reasonable to assume that these attenuation maxima should be associated with intrinsic effects and not with the grain structure of the samples. It was possible to make attenuation measurements on one $YBa_2Cu_3O_7$ sample at several frequencies when only the

low temperature maximum was investigated. The maximum moved up in temperature for the higher frequencies, indicating that this maximum is not produced by a phase transition but by a relaxation mechanism between an excited state and a ground state. Analysis of the temperature dependence of the relaxation time derived from these measurements yields an activation energy for the excited state of about 400 K, which is close to the Debye temperature of $YBa_2Cu_3O_7$.

If it is assumed that the high temperature maximum is also due to a relaxation mechanism, then an activation energy of about 1100 K is obtained for the relaxation time. This value for the interacting excitations is close to that required by the interaction mechanism, exchange of soft plasmons, which was proposed by V. Kresin for producing the high T_c's of the perovskite superconductor.

Work is in progress to try to determine the frequency dependence of the temperature position of this maximum in order to ascertain its origin.

C. $Ba_{0.625}K_{0.375}BiO_3$

Both the perovskite and tetragonal structure high T_c superconductors contain CuO planes in their unit cells. It has been postulated that these CuO planes are essential in the production of high T_c. Recently a superconducting system has been investigated at Argonne National Laboratory which does not contain Cu and which has T_c's close to 30K. It has been proposed that superconductivity in this system is produced by BCS like electron-phonon interaction with a resulting superconducting energy gap. Preliminary ultrasonic attenuation measurements were done on a sample of $Ba_{0.625}K_{0.375}BiO_3$ at 33 MHz. Although no effect has been observed near T_c = 28 K, a maximum in attenuation is seen at around 50 K. Both velocity and attenuation meaurements will be performed on this sample close to T_c in

order to detect any possible effects that may occur. Such observations may help to determine if a BCS superconducting state exists in this system.

D. UPt_3

UPt_3 is a heavy Fermion superconductor with an anisotropic energy gap, wherein the gap may vanish at the poles if it is an axial superconductor or at the equator if is a polar superconductor. It is likely that if an energy gap exists in the high T_c superconductors, then it will be anisotropic. Ultrasonic measurements are being performed on UPt_3 in order to determine the types of interactions that may occur in the presence of an anisotropic energy gap, and the information that may be extracted from such observations. The temperature dependence of the attenuation in a superconductor with an isotropic energy gap is exponential; with a polar one, it is quadratic; and, with an axial one, it is cubic. Our measurements on UPt_3 indicate a quadratic dependence at low temperatures and a cubic dependence close to T_c.

Our attenuation measurements as a function of magnetic field have shown a peak in attenuation in the mixed state of UPt_3. This peak has also been observed in other laboratories. We postulate that this peak is due to a phase transition of the flux line lattice which is driven by the anisotropy of the energy gap which in turns produces an anisotropic superconducting density around the flux lines.

These measurements, together with those which have been performed on reentrant superconductors, should help in the analysis and understanding of the ultrasonic attenuation data that are being obtained on the high T_c superconductors.

IV. Publications

A. Papers submitted to Refereed Journals (Not yet published)

1. Magnetic Field Dependent Sound Attenuation in UPt_3,
A. Schenstrom, M-F. Xu, Y. Hong, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, J. B. Ketterson and D. Hinks
18 Rare Earth Research Conference, Lake Geneva (1988),
to be published in J. of the Less Common Metals.

2. Hysteresis in Ultrasonic Attenuation of UPt_3 in Low Magnetic Fields.
A. Schenstrom, M-F. Xu, Y. Hong, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, J. B. Ketterson and D. Hinks
18 Rare Earth Research Conference, Lake Geneva (1988),
to be published in J. of the Less Common Metals.

3. Ultrasonic Attenuation in Sinter-forged High Tc Superconductor $YBa_2Cu_3O_{7-\delta}$
M-F. Xu, Y. Hong, M. Levy, B. K. Sarma, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier and J. B. Ketterson,
18 Rare Earth Research Conference, Lake Geneva (1988),
to be published in J. of the Less Common Metals.

4. Ultrasonic Velocity Anomalies in Sinter-forged High Tc Superconductor $YBa_2Cu_3O_{7-\delta}$
Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier J. B. Ketterson, M-F. Xu, Y. Hong, M. Levy and B. K. Sarma,
18 Rare Earth Research Conference, Lake Geneva (1988),
to be published in J. of the Less Common Metals.

5. Frequency Dependent Ultrasonic Attenuation of $YBa_2Cu_3O_7$, K. J. Sun, W. P. Winfree, M-F. Xu, B. K. Sarma, M. Levy, R. Caton and R. Selim, Phys. Rev. B (1988). Rapid Communication. (Accepted for publication).

6. Ultrasonic Velocity Anomalies in Superconducting Sinter-forged $YBa_2Cu_3O_{7-\delta}$ Z. Zhao, S. Adenwalla, A. Moreau, J. B. Ketterson, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier, M-F. Xu, Y. Hong, R. F. Wiegert, M. Levy and B. K. Sarma, (Submitted to Phys. Rev.).

7. Ultrasonic Attenuation Measurements in Sinter-forged $YBa_2Cu_3O_{7-\delta}$ M-F. Xu, D. Bein, R. F. Wiegert, B. K. Sarma, M. Levy, Z. Zhao, S. Adenwalla, A. Moreau, Q. Robinson, D. L. Johnson, S. J. Hwu, K. R. Poeppelmeier and J. B. Ketterson, (Submitted to Phys. Rev.).

8. Anisotropy of the Magnetic Field Induced Transition in Superconducting UPt_3 A. Schenstrom, M. F. Xu, Y. Hong, D. Bein, M. Levy, B. K. Sarma, S. Adenwalla, Z. Zhao, T. Tokuyasu, D. Hess, J. B. Ketterson, J. A. Sauls and D. G. Hinks, (Submitted to Phys. Rev. Lett.).

B. Invited Presentations at Topical or Scientific/Technical Society Conferences

Moises Levy: "Ultrasonic Investigation of Novel Superconductors" at the Engineering Conference and Exposition, MECCA, Milwaukee, WI, April 13-14, 1988

Moises Levy: "Ultrasonic Properties of Oriented Ceramic High T_c Superconductors" IEEE 1988 Ultrasonics Symposium, Chicago, IL, October 2-5, 1988